Systems Engineering Applied to Fielded Systems

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Outline

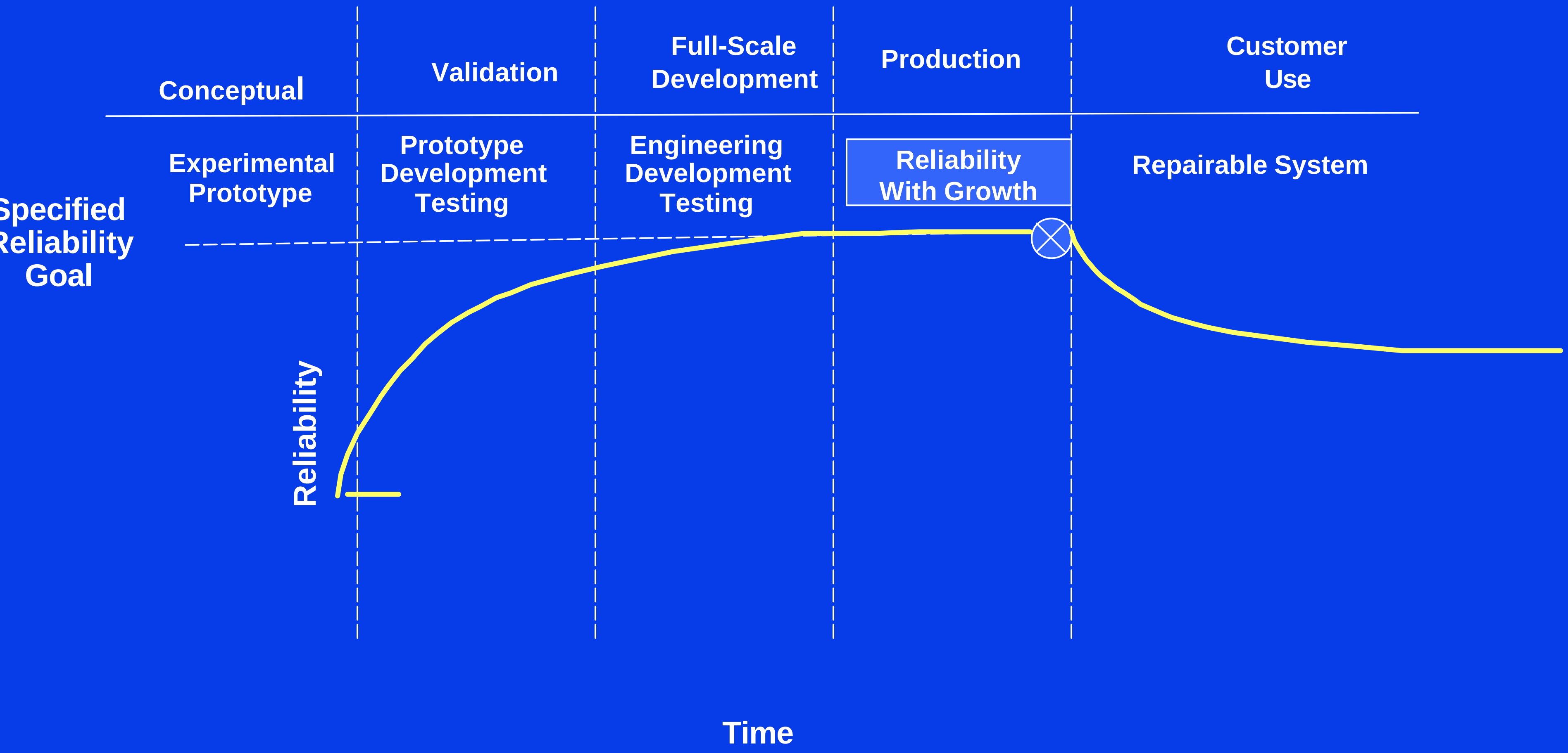
- Problem
- Background on Methodology
- Application of Methodology to solve problem
- Examples
- Conclusion

Problem

Problems That are Receiving Increased Attention

- **Cost to Maintain Fleet of Aircraft**
- **Maintaining Mission Reliability as System Ages**
- **Determine Optimum Repair and Overhaul Strategy to Minimize Life Cycle Cost**
- **Determining Corrective Actions for Fielded Systems to Upgrade Reliability and Reduce Cost**
- **Determining the Wear out Profile for Fielded System as the System Ages**

RELIABILITY
IN DESIGN AND TEST, AND CUSTOMER USE



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Problem

- Systems Engineering Generally Addresses Reliability, Reliability Growth, Spares, and Overhaul Policies in the Design Phase
- The Overhaul Policies Set in Design Phase May Not Be Optimum
- Actual Field Failure Data and Cost Information Can Help Define More Optimum Policies
- Also, After the System Is Fielded Reliability Information May Uncover Deficiencies , and Opportunities for Reliability Growth to Reduce Costs
- Technology Improvements for Reliability May Also Reduce Failures- and Repair and Overhaul Costs

SE Methodologies To Reduce Fleet Costs

Two Methods to Help Reduce Costs

- Overhaul Policy
  – For a System That Is Overhauled "What Is the Optimum Overhaul Time That Will Minimize Total Life Cycle Cost?—Economical Life
  – Useful Life Considers the Tradeoff Between Economic Life and Maintaining a Minimum Mission Reliability Capability Between Overhauls
- Reliability Growth
  – What Is the Improvement in the System Reliability Resulting From Proposed Corrective Actions
  – What Is the Fleet Cost Savings If These Corrective Actions Are Implemented

CONCEPT OF MINIMAL REPAIR

- **Minimal Repair**
- **The Repair of a Single Failure Mode Upon Failure Does Not Greatly Improve the System Reliability From What It Was Just Before Failure**
- **Nonhomogeneous Poisson Process (NHPP) Model**
- **Failure Intensity**

u(t)Dt - The probability of system failure in (t,t+Dt) regardless of whether or not

the system has failed in (0,t)

POWER LAW POISSON PROCESS

- Non-homogeneous Poisson Process Model
- Failure Intensity

  $U(t) = l\,b\,T^{b-1}$ T>0 l, b PARAMETERS

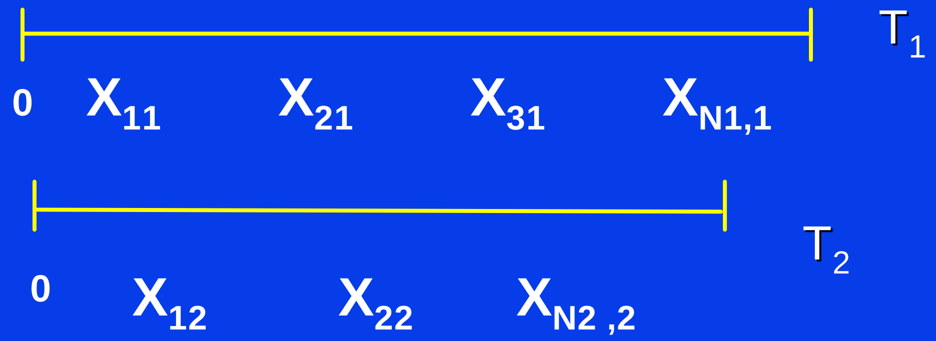
- Can Estimate l , b From Data
- Crow (1974) - Introduced Power Law Model and Estimated Procedures for Multiple Systems

$\beta<1$	$\beta=1$	$\beta>1$
Reliability Improvement	Constant	Wear out

GENERAL EQUATIONS

Systems in Fleet Have Repeated Overhaul Cycles

- **ML Estimates**



$$\hat{l} = \frac{\sum_{q=1}^{K} N_q}{\sum_{q=1}^{K} \left(T_q^{\hat{b}} \right)}$$

$$\hat{b} = \frac{\sum_{q=1}^{K} N_q}{\hat{l} \sum_{q=1}^{K} \left[T_q^{\hat{b}} Ln(T_q) \right] - \sum_{q=1}^{K} \sum_{i=1}^{Nq} Ln(X_{iq})}$$

EXAMPLE-Life Cycle Cost Model

Nominal Overhaul Time T = 1500

System	Failure Times	OH Time
1	68, 1137,1167	1268
2	682, 744, 831	1300
3	845	1593
4	263, 399	1421
5		1574
6		1415
7	598	1290
8		1556
9		1426
10	730	1124
11		1568

Optimum Overhaul Policy

- Parameter Estimates
- l = 0.000002558 b = 1.774
- C_1 = \$29,860 Cost of Repair
- C_2 = \$100,000 Cost of Overhaul
- Optimum Overhaul Time to Minimize Life Cycle Cost

$$T_O = \left[\frac{C_2}{l(b-1)C_1} \right]^{1/b}$$

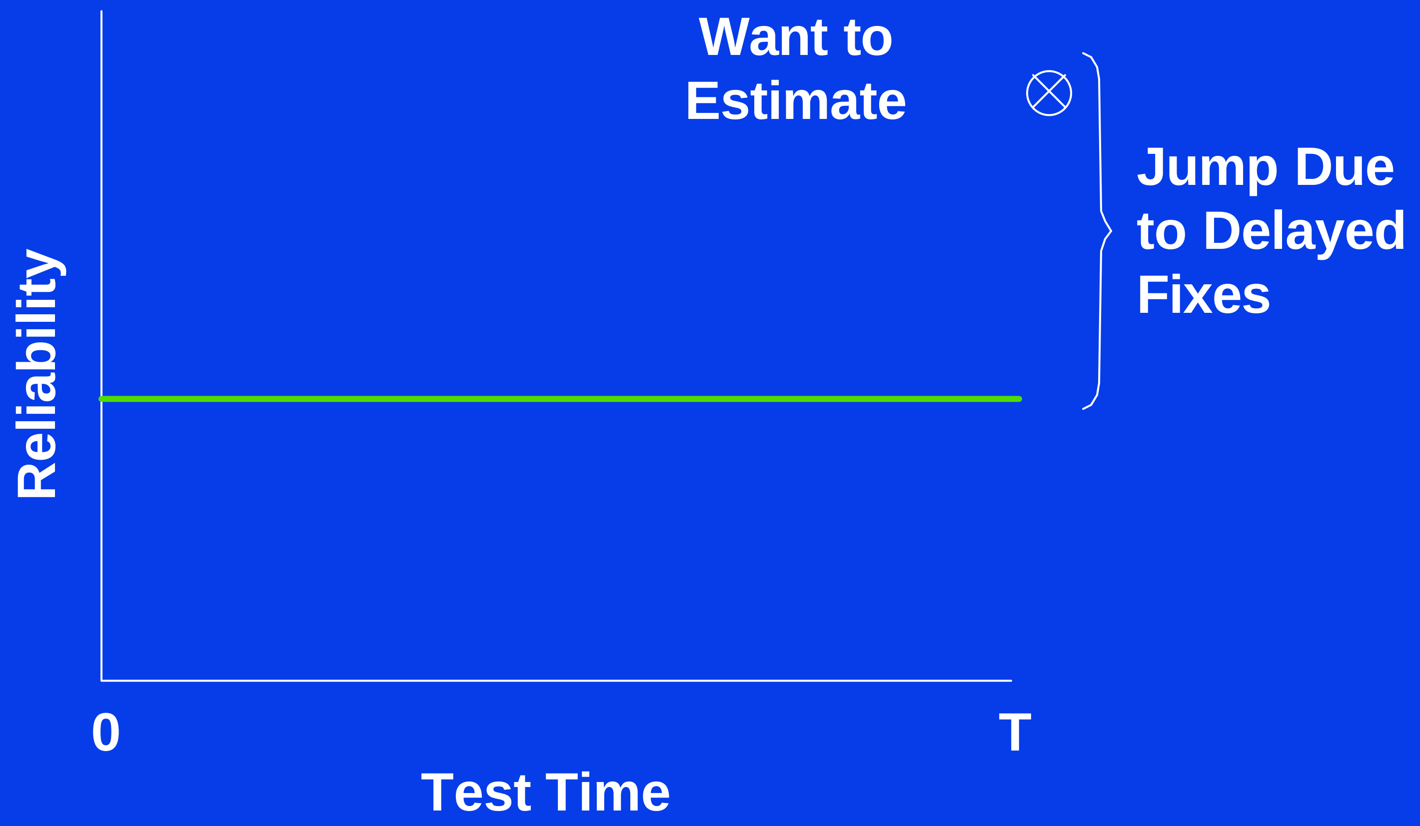
T_O=3237 hours

Optimum Overhaul Policy
Cost Savings

- Current Overhaul Time 1500 Hours
- 3 hour Mission Reliability Requirement 0.995
- R(1500) = 0.996 Cost/hr = $88.56
- R(3237) = 0.993 Cost/hr = $70.65
- R(2060) = 0.995 Cost/hr = $76.66
- Cost Savings per Hour (2060) =$11.90
- 79,000 Fleet Hours per Year
- Annual Cost Savings(2060) = $940,000.

RELIABILITY PROJECTION MODEL

Crow (1983)



RELIABILITY PROJECTION MODEL

- **Type A Modes**

  All Modes Such That If Seen During Test No Corrective Action Will Be Taken. This Accounts for All Modes for Which It Is Not Cost-effective to Attempt to Increase the Reliability by a Design Change.

- **Type B Modes**

  All Modes Such That If Seen a Design Change, or Fix, Will Be Attempted

- **d – Average Effectiveness Factor - the Fraction Decrease in Failure Rate After a Corrective Action (Typical d= .70)**

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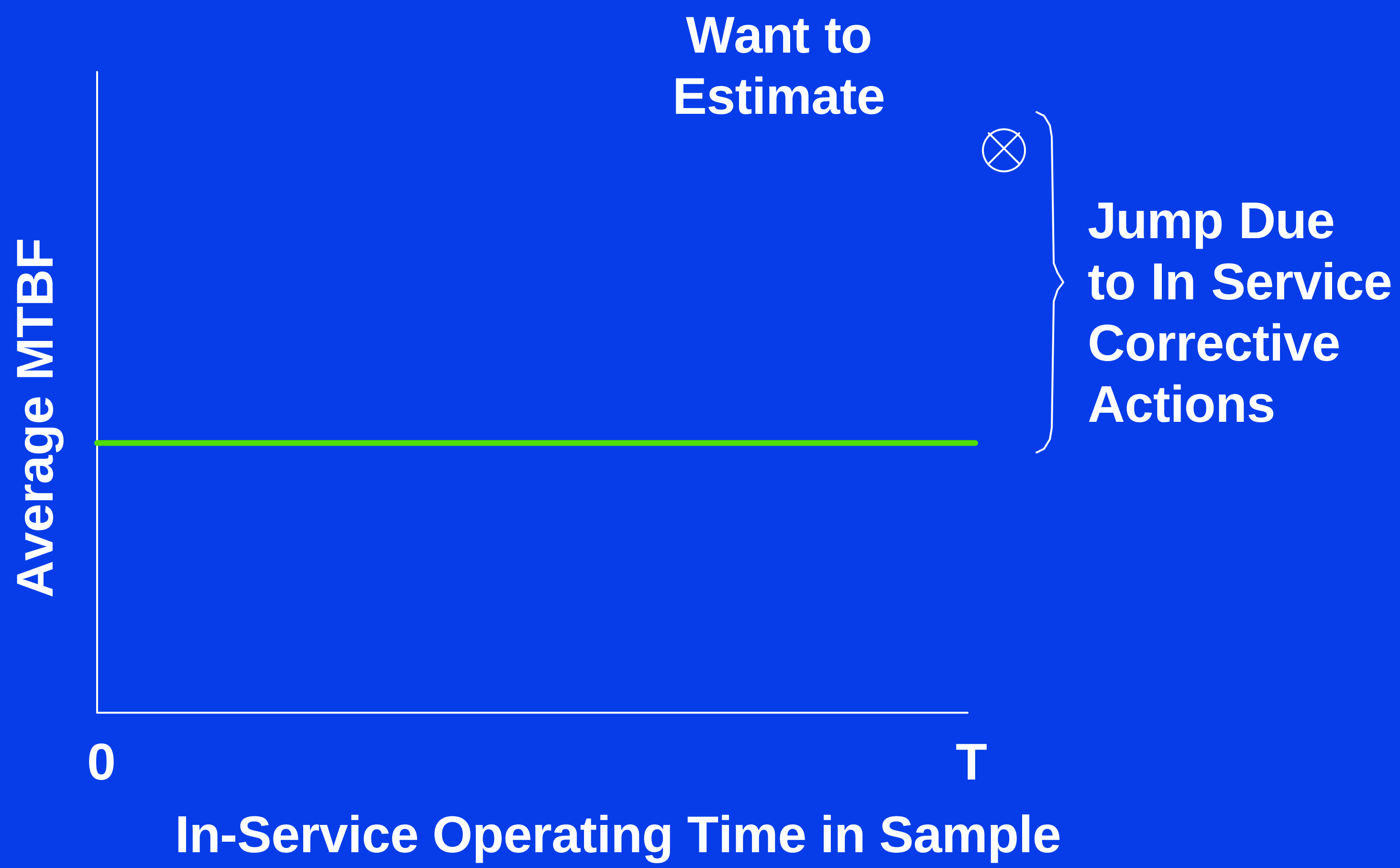
RELIABILITY PROJECTION
Application to In-Service Reliability Growth



K=27 Systems N = 37 Failures

EXAMPLE

Sys	Cycle	Ni	Failures
1	1396	1	1396
2	4497	1	4497
3	525	1	525
4	1232	1	1232
5	227	1	227
6	135	1	135
7	19	1	19
8	812	1	812
9	2024	1	2024
10	943	2	316,943
11	60	1	60
12	4234	2	4233, 4234
13	2527	2	1877, 2527
14	2105	2	2074, 2105

For Projection Model Convert Failure Data to Accumulated Operating Times

$Y_1 = 1396$

$Y_2 = 5893$

$Y_3 = 6418$

$Y_{37} = 52110$

Each Failure Corresponds To a Failure Mode that will not be corrected (A Mode) Or will be corrected (B Mode)

T = 52110 Total Accumulated Operating On All 27 Systems in the Sample

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EXAMPLE

Ordered Failure Data and Type A and Distinct Type B Modes (K = 27 Systems, N = 37 Failures, T = 52110)

Category A and B Classification								
1396 B1	5893 B2	6418 A	7650 B3	7877 B4	8012 B2	8031 B2	8843 B1	10867 B1
11183 B5	11810 A	11870 B1	16139 B2	16104 B6	18178 B7	18677 B2	20751 B4	
20772 B2	25815 B1	26361 B1	26392 A	26845 B8	30477 B1	31500 A	31661 B3	
31697 B2	36428 B1	40223 B1	40803 B9	42656 B1	42724 B10	44554 B1	45795 B11	
46666 B12	48368 B1	51924 B13	52110 B2					

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EXAMPLE

- **Can Now Apply Reliability Projection Model to In-Service Reliability Growth**

$$l_S = \frac{37}{52110}$$

Average MTBF = 1408

Before Corrective Actions

EF d = .4

M = 13 Corrective Actions

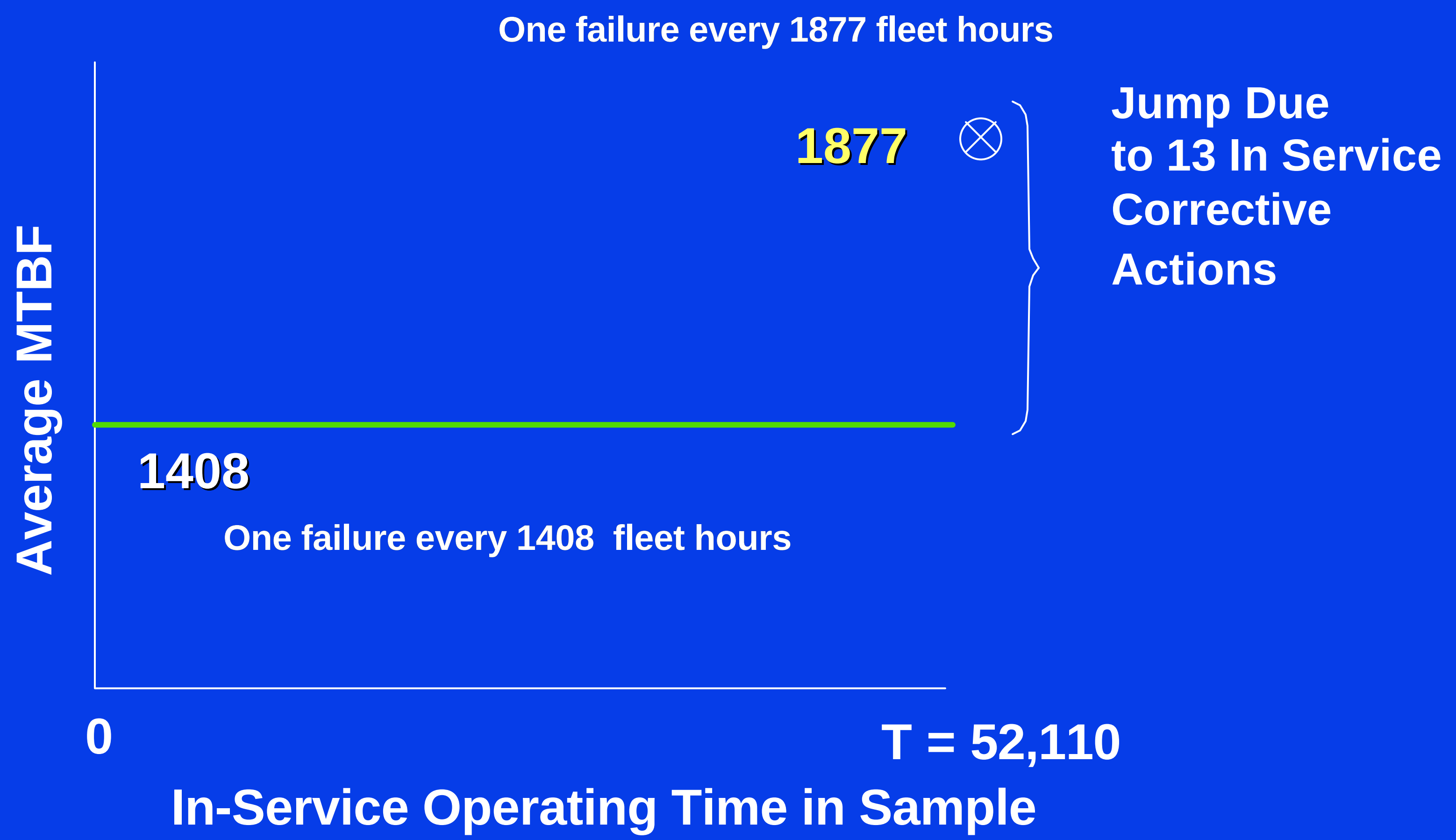
$$l_P = .00053$$

New Average MTBF = 1877

After Corrective Actions

One failure every 1877 fleet hours

RELIABILITY PROJECTION



COST SAVINGS

- Average of 440,000 Fleet Hours Per Year
- 74 % of Failures Result in Overhaul
- Current (1408) Have Average of 231 Overhauls Per Year
- Projected(1877) Will Have Average of 173 Overhauls Per Year
- $60,000 Cost Per Overhaul
- Estimated Annual Cost Savings = **$3,480,000**.

Conclusions

- Can Apply Systems Engineering Reliability Methods Used in Design to Reduce In-Service Fleet Costs
- Methods are Easy to Apply
- Methods Discussed Are Successfully Being Used by DoD and Industry to Address Reliability and Fleet Costs.
- Have Presented Examples Illustrating Applications